The present invention provides a method and apparatus for regulating pressure within a closed expansion system. In one aspect of the invention, the apparatus comprises an expander tool comprising a first pressure regulation system disposed within an expansion chamber. The first pressure regulation system comprises two valves which regulate pressure within the expansion system during run-in. In another aspect of the invention, the apparatus comprises an expander tool comprising an expansion chamber in fluid communication with a second pressure regulation system. The second pressure regulation system regulates pressure during the expansion of a tubular. The second pressure regulation system comprises a frangible member and a valve in series, and optionally a pressure regulator downstream of the frangible member and valve in series. In another aspect of the invention, a method is provided for regulating pressure during the expansion process using the first and/or second pressure regulation system.
MULTI-PRESSURE REGULATING VALVE SYSTEM FOR EXPANDER

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

The present invention relates to wellbore completion. More particularly, the invention relates to an expansion system for expanding strings of casing within a wellbore. More particularly still, the invention relates to an apparatus and method for regulating expansion force in an expander tool for expanding a tubular body. More particularly still, the apparatus relates to a valve system for regulating pressure within an expansion chamber during expansion of the strings of casing as well as during run-in of the expansion system into the wellbore.

[0002] 2. Description of the Related Art

Hydrocarbon and other wells are completed by forming a borehole in the earth and then lining the borehole with steel pipe or casing to form a wellbore. After a section of wellbore is formed by drilling, a string of casing is lowered into the wellbore and temporarily hung therein from the surface of the well. Using apparatus known in the art, the casing is cemented into the wellbore by circulating cement into the annulus area defined between the outer wall of the casing and the borehole. The combination of cement and casing strengthens the wellbore and facilitates the isolation of certain areas of the formation behind the casing for the production of hydrocarbons.

[0003] It is common to employ more than one string of casing in a wellbore. In this respect, a first string of casing is set in the wellbore when the well is drilled to a first designated depth. The first string of casing is hung from the surface, and then cement is circulated into the annulus behind the casing. The well is then drilled to a second designated depth, and a second string of casing, or liner, is hung into the well. The second string is set at a depth such that the upper portion of the second string of casing overlaps the lower portion of the first string of casing. The second liner string is then cemented and “hung” off of the existing casing by the use of slips which utilize slip members and cones to wedgily fix the new string of liner in the wellbore. The second casing string is then cemented. This process is typically repeated with additional casing strings until the well has been drilled to total depth. In this manner, wells are typically formed with two or more strings of casing of an ever-decreasing diameter.

[0004] Apparatus and methods exist that permit tubulars to be expanded within a wellbore. The apparatus typically includes expander tools which are fluid powered and are run into the wellbore on a working string. The hydraulic expander tools include radially expandable members which, through fluid pressure, are urged outward radially from the body of the expander tool and into contact with a tubular therearound. As sufficient pressure is generated on a piston surface behind these expansion members, the tubular being acted upon by the expansion tool is expanded past its point of elastic deformation. In this manner, the inner and outer diameters of the tubular are increased in the wellbore. By rotating the expander tool in the wellbore and/or moving the expander tool axially in the wellbore with the expansion member actuated, a tubular can be expanded into plastic deformation along a predetermined length in a wellbore.

[0005] A known apparatus used to expand tubulars in a wellbore is a closed system expander tool. A closed system expander tool comprises an expansion chamber which contains hydraulic fluid. The hydraulic fluid is inserted into the expansion chamber before the expander tool is run into the wellbore. In this way, it is not necessary to introduce hydraulic fluid into the wellbore from the surface after the expander tool is run into the wellbore to actuate the expander tool. Rather, fluid pressure from within the expansion chamber actuates the expander tool.

[0006] Multiple uses for expandable tubulars are being discovered. For example, an intermediate string of casing can be hung off of a string of surface casing by expanding an upper portion of the intermediate string into frictional contact with the lower portion of surface casing therearound. This allows for the hanging of a string of casing without the need for a separate slip assembly as described above. Additional applications for the expansion of downhole tubulars exist. These include the use of an expandable sand screen, deployment of an expandable seat for seating a diverter tool, and the use of an expandable seat for setting a packer.

[0007] One problem with existing closed expansion systems is the risk of collapse of the expander tool due to differential pressures between the inside and the outside of the expansion chamber as the expander tool is run into the wellbore. When the expansion system is operated as a closed system, a difference in pressure develops between the annular area which is between the outer diameter of the expander tool and the inner diameter of the casing string to be expanded, and the expansion chamber of the closed expansion system. The difference in pressure between the two areas can result from air pockets trapped in the closed system or from thermal expansion of fluid in the closed system. Trapped air pockets in the closed expansion system cause the pressure of the annular space to become higher than the pressure of the closed expansion system, as the trapped air in the expansion system creates a pressure drop within the expansion system relative to the annular space. This pressure differential causes stress upon the outside of the expansion chamber. In contrast, thermal expansion of fluid within the expansion system causes the pressure of the closed expansion system to become higher than the pressure in the annular space. Often, the temperature within the wellbore is much higher than the temperature at the surface. The hydraulic fluid within the expansion chamber may expand in volume due to the heat as the expander tool is run into the wellbore, thus creating a stress on the inside of the expansion chamber. The pressure differential created either by trapped air pockets or thermal expansion of fluid in the closed system increases the risk of collapse of the expansion system during run-in.

[0008] An additional problem with the prior art expansion systems occurs during the expansion process itself. The expansion process begins after the expander tool is lowered to a desired depth within the wellbore. The expander tool is rotated and pressure is exerted onto the tubular to be expanded by the expander tool, causing the tubular material to expand radially. The expander tool initially expands the tubular radially outward through the annular space. Next, the tubular being expanded hits the constraint point, which is typically the inner diameter of the well casing within the wellbore. After hitting the constraint point, the expander tool
is moved axially as well as radially so that the tubular is expanded throughout the length of the tubular.

[0011] Greater pressure is required to initiate expansion than to maintain expansion after hitting the constraint point. Therefore, more pressure is necessary at the beginning of the expansion process than is necessary to maintain expansion along the length of the tubular being expanded. Existing expansion systems allow pressure exertion on the tubular at the same rate throughout the expansion process. Expansion at the same rate throughout the process over-expands the tubular after the tubular hits the constraint point, creating excessive thinning of the tubular wall when the expander tool is allowed to expand the length of the tubular while rotating and moving axially.

[0012] Therefore, a need exists for a pressure regulation system for an expander tool which effectively regulates the pressure differential between the annular space and the expansion chamber during run-in of the expander tool. Further, a need exists for a pressure regulation system for an expander tool which regulates pressure during the expansion process, allowing the expander tool to exert greater pressure during initial expansion to the constraint point and lesser pressure to maintain expansion after hitting the constraint point. Further still, there is a need for a pressure regulation system for an expander tool which aids in gradual transition within the expansion chamber of the expander tool from the initial pressure to the pressure necessary to maintain expansion.

SUMMARY OF THE INVENTION

[0013] The present invention provides an apparatus for expanding a tubular body. More specifically, improved pressure regulation systems for an expander tool are disclosed. In addition, the present invention provides a method for expanding a tubular body, such as a string of casing within a hydrocarbon wellbore, which employs the improved pressure regulation systems of the present invention.

[0014] The expansion system of the present invention comprises two pressure regulation systems. Both pressure regulation systems may be combined to produce a complete system for run-in and operation of the expansion system, or, in the alternative, either of the systems may be utilized in the expansion process separately.

[0015] The first pressure regulation system allows for pressure regulation during run-in of the expansion system to equalize fluid pressure between the annular space and the expansion chamber within the expansion system, thus preventing collapse of the expansion system. The first system comprises at least two valves which are located internal to the expansion chamber of the expander tool. The first valve allows pressure to exit from the expansion chamber into the annular space, while the second valve allows pressure to exit from the annular space into the expansion chamber.

[0016] The first pressure regulation system operates upon run-in of the expansion system. After the expansion tool is run into the depth at which the expansion process is to be performed, both valves are isolated from the expansion process. Isolation occurs when the valves are plugged, thus preventing fluid flow through the two valves.

[0017] The second pressure regulation system is activated when expander tool has been run into the desired depth for the tubular expansion. The second system regulates pressure during the expansion process. The expansion process occurs in two stages, each stage requiring a different pressure within the expansion chamber. In the first stage, an initial, high pressure is required to build up enough fluid pressure within the expansion chamber to urge the radically expandable members of the expander tool radially from the body of the expander tool and into contact with the tubular therearound, as well as to expand the tubular past its point of elastic deformation and into the surrounding wellbore. In the second stage, a lower pressure is necessary to maintain the radically expandable members of the expansion tool in contact with the tubular therearound while expanding the tubular into plastic deformation along the predetermined length in the wellbore by rotation and axial movement of the tubular within the wellbore.

[0018] Regulation of fluid pressure within the expansion chamber at two predefined levels is accomplished by the second pressure regulation system. In one embodiment, the second pressure regulation system comprises a check valve and a frangible member in fluid communication with the expansion chamber of the expansion system. The check valve and the frangible member are placed in series. The frangible member, which is preferably a burst plug, permits the appropriate amount of fluid pressure to build up within the expansion chamber to accomplish initial expansion of the tubular by inhibiting flow through the plug until a designated pressure is reached within the expansion chamber. When the pressure necessary for initial expansion of the tubular is achieved and the tubular reaches the constraint point, the frangible member bursts, thus allowing a pressure drop sufficient to prevent excessive thinning of the tubular wall. The check valve then begins to regulate the pressure within the chamber of the expansion tool by cycling from open to closed. The check valve permits a lesser amount of fluid pressure to remain within the expansion chamber so that the expansion process is completed without overexpanding the tubular walls.

[0019] In another embodiment, the second pressure regulation system may further comprise a pressure regulator to control pressure downstream of the frangible member and check valve in series. The pressure regulator is preferably a jetted valve. The pressure regulator creates a back pressure on the check valve, increasing the ability of the check valve to cycle open to closed. The role of the pressure regulator involves providing a smooth, efficient transition from the higher pressure in the expansion chamber required for initial expansion of the tubular to the lower pressure necessary to maintain expansion.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0021] FIGS. 1A-C depict a longitudinal cross-sectional view of a closed expansion system which might be used with
the present invention, with the pressure regulation systems of the present invention located in the closed expansion system. FIG. 1A is the top portion of the expansion system, FIG. 1B is the middle portion of the expansion system, and FIG. 1C is the bottom portion of the expansion system. The expansion system is shown in the run-in configuration.

[F0022] FIGS. 2A-C show the expansion system of FIGS. 1A-C disposed within a wellbore after being run into the wellbore, during the initial expansion.

[F0023] FIG. 3 is a longitudinal cross-sectional view of a portion of the expansion system of FIG. 1 disposed within a wellbore at the end of the expansion process.

[F0024] FIG. 4 is an expanded cross-sectional view of one embodiment of the second pressure regulation system of the present invention shown in FIG. 1.

[F0025] FIG. 5 is an expanded cross-sectional view of another embodiment of the second pressure regulation system of the present invention shown in FIG. 1.

[F0026] FIG. 6 is an expanded cross-sectional view of the first pressure regulation system of the present invention shown in FIG. 1.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[F0027] FIGS. 1A-C, 2A-C, and 3 are depictions of an expander tool that is part of a closed expansion system which may utilize the pressure regulation systems of the present invention. The pressure regulation systems of the present invention are designed for use in a closed expansion system, including but not limited to the closed expansion system shown in FIGS. 1A-C, 2A-C, and 3.

[F0028] FIGS. 1A-C show the expansion system in the run-in configuration. An upper casing string 31 and a lower casing string 32 are disposed within a wellbore. In the run-in configuration, the lower casing string 32, or liner, is lowered into the wellbore co-axially with the upper casing string 31 by a casing working string (not shown). The lower casing string 32 is ultimately positioned such that an upper portion of the lower casing string 32 overlaps with a lower portion of the upper casing string 31. A collet (not shown) may be used to support the lower casing string 32 on the casing working string.

[F0029] The lower casing string 32 serves as an expandable tubular. In particular, the lower casing string 32 will be hung in the upper casing string 31 by expanding the upper portion of the lower casing string 32 into the lower portion of the upper casing string 31, as shown in FIG. 2B. However, it is understood that the apparatus and method of the present invention may be utilized to expand downhole tubulars other than strings of casing.

[F0030] A sealing member (not shown) may be disposed on the outer surface of the lower casing string 32 in order to seal an annular area 33 between the lower outer surface of the lower casing string 32 and the inner surface of the outer casing string 31 as the upper portion of the lower casing string 32 is expanded. Suitable sealing members for preventing fluid flow through the annular space during expansion are known by those skilled in the art. Also disposed on the outer surface of the lower casing string 32 is at least one slip member (not shown) to provide an improved grip between the lower casing string 32 and the upper casing string 31 during expansion of the lower casing string 32. Again, suitable slip members for use in the expansion process are known to those skilled in the art.

[F0031] In order to expand the lower casing string 32 into the upper string of casing 31 as seen in FIG. 3, an expander tool 2 is provided. For clarity purposes, portions of the expander tool 2 which represent the pressure regulation systems of the present invention have been enlarged in FIGS. 4, 5, and 6. Therefore, FIGS. 1A-C are described in conjunction with reference to FIGS. 4, 5, and 6, with like elements similarly labeled.

[F0032] As shown in FIGS. 1A-C, the expander tool 2 includes a rotatable mandrel 3 connected to an upper running tool (not shown) with a torque anchor (not shown) thereon at an upper end and a bottom connector 45 at a lower end. Torque screw threads (not shown) may be used to connect the rotatable mandrel 3 to the upper running tool so that the upper running tool may transfer torque to the rotatable mandrel 3. The bottom connector 45 may be used to connect other tools to the expander tool 2.

[F0033] A lower spline assembly 49 is coupled to a lower portion of the rotatable mandrel 3 using a first spline connection 52. The lower spline assembly 49 includes a lower inner spline 50 at least partially disposed in a lower outer spline 51. The lower inner spline 50 shown in FIGS. 1A-B comprises four members 50A, 50B, 50C, and 50D, and the members 50A, 50B, 50C, and 50D are connected by pins. It is to be understood that the lower inner spline 50 may comprise one or more members. The members 50A, 50B, 50C, and 50D of the lower inner spline 50 translate together and house one or more expandable members 15. Preferably, the lower inner spline 50 and the lower outer spline 51 are tubular shaped and are coupled to each other using a second spline connection 53. Specifically, the second spline connection 53 consists of grooves formed on an inner surface of the lower outer spline 51 which mate with splines formed on an outer surface of the lower inner spline 50. The first spline connection 52 coupling the lower spline assembly 49 to the rotatable mandrel 3 includes splines formed on an inner surface of a lower portion of the lower outer spline 51 which mates with grooves formed on an outer surface of the rotatable mandrel 3. The first and second spline connections 52 and 53 allow the rotatable mandrel 3 to transfer torque to the lower inner spline 50 when the mandrel 3 is rotated. The second spline connection 53 also allows the lower inner spline 50 to extend and/or retract axially relative to the lower outer spline 51.

[F0034] The expander tool 2 contains an annular space formed between the lower inner spline 50 and the rotatable mandrel 3. The annular space acts as an expansion chamber 54 for containing hydraulic fluid used to actuate one or more of the expandable members 15 disposed in the lower inner spline 50. Seals such as o-rings may be used to prevent fluid leakage from the expansion chamber 54. As shown in FIG. 6, lower seals 56 attached to the lower inner spline 50 are disposed between the rotatable mandrel 3 and the lower inner spline 50. By attaching the lower seals 56 to the lower inner spline 50, the lower seals 56 travel with the lower inner spline 50 during operation. To effectively retain the fluid, the lower seals 56 contact a mandrel taper 55 of pre-determined length formed on an outer surface of the mandrel 3. The
mandrel taper 55 allows the lower seals 56 to seal in the fluid as they travel with the lower inner spline 50. When the lower seals 56 move past the end of the mandrel taper 55, the fluid is allowed to drain out of expansion chamber 54. Fluid is introduced into the expansion chamber 54 prior to lowering the expander tool 2 into the wellbore.

[0035] Pressure in the expansion chamber 54 is controlled during run-in of the expansion system using a first pressure regulation system 5, which is located within the expansion chamber 54 of the expander tool 2, preferably located within the lower inner spline 50. The first pressure regulation system 5 comprises a first valve 57 on one side of the expansion chamber 54 and a second valve 58 on the other side of the expansion chamber 54, the two valves 57 and 58 disposed in between the lower seals 56. Preferably, the first pressure regulation system 5 is disposed below the expandable members 15 of the expander tool 2. The first pressure regulation system 5 is shown in FIG. 6. The first pressure regulation system 5 also comprises a fluid recess 90 between the rotatable mandrel 3 and the lower inner spline 50. As shown in the run-in configuration in FIG. 1C, the first valve 57 allows fluid pressure to flow into the annular space between the wellbore and the expander tool 2 from the expansion chamber 54, while the second valve 58 allows fluid pressure to flow from the expansion chamber 54 into the annular space between the wellbore and the expander tool 2.

[0036] The lower inner spline 50 has a plurality of recesses 17 to hold expandable members 15 capable of extending radially. The expandable members 15 suitable for use in the present invention include, but are not limited to, expander pads and expander rollers. The expandable members 15 are supported on a piston 16 and may be disposed within a cartridge 18 to facilitate replacement. The cartridge 18 is then attached to the recess 17 in the lower inner spline 50. The back of the piston 16 is exposed to the fluid pressure in the expansion chamber 54. As the pressure is increased, the fluid forces the pistons 16 from the recesses 17. This, in turn, causes the expandable members 15 to contact the lower casing string 32. Although two expandable members 15 are shown in FIG. 1B, additional expandable members 15 may be added to the expander tool 2. Furthermore, only one recess 17/piston 16/cartridge 18/expandable members 15 assembly is depicted in FIG. 1B. Any number of assemblies may be utilized in the present invention.

[0037] Also located inside the expansion chamber 54 is a second pressure regulation system 70. The second pressure regulation system 70 regulates fluid pressure inside the expansion chamber 54 during the expansion process, after the expander tool 2 is run into the location at which the lower casing string 32 is to be expanded. The second pressure regulation system 70, as seen in FIGS. 4 and 5 as well as FIG. 1B, is located in between the outer diameter of the rotatable mandrel 3 and the inner diameter of the lower inner spline 50. Reciprocable threads 76, 77 are located on the outer diameter of the rotatable mandrel 3 and on the inner diameter of the second pressure regulation system 70, respectively. Also, a tubular member 80 is threadably connected to the lower inner spline 50. The reciprocable threads 76, 77 are disposed above and below a frangible member 71 and a check valve 72 in series. The check valve 72 is disposed downstream of the frangible member 71 with respect to fluid exiting the expansion chamber 54, so that the frangible member 71 is closest to and is in fluid communication with the expansion chamber 54. In the preferred embodiment shown in FIG. 5, a pressure regulator valve 73 may be located downstream from the check valve 72. The pressure regulator 73 is closest to and in fluid communication with the annular space 75 outside the expansion chamber 54 in another embodiment depicted in FIG. 4, the check valve 72 is closest to and in fluid communication with the annular space 75 outside the expansion chamber 54. In this embodiment, the pressure regulator valve 73 is not utilized. In either embodiment, upper seals 74 are located on the second pressure regulation system 70 to seal the annular space between the second pressure regulation system 70 and the lower inner spline 50.

[0038] The frangible member 71 is any member which prevents fluid from flowing through the frangible member 71 from the expansion chamber 54 until a certain predetermined pressure is reached within the expansion chamber 54. The frangible member 71 prevents fluid flow from the expansion chamber 54 to the annular space 75 so that enough pressure builds up within the expansion chamber 54 to activate the expandable members 15 of the expander tool 2. When a sufficient pressure to perform initial expansion of the lower casing string 32 is reached within the expansion chamber 54, the frangible member 71 breaks, placing the expansion chamber 54 in fluid communication with the check valve 72. Preferably, a burst plug is used as the frangible member 71. Burst plugs are known to persons skilled in the art. The check valve 72 is a valve that cycles from open to closed, allowing fluid to flow in one direction while preventing fluid flow in the opposite direction. In the present invention, the check valve 72 allows fluid to flow from the expansion chamber 54 into the annular space 75 in the embodiment shown in FIG. 4 and into the pressure regulator 73 in the embodiment shown in FIG. 5. Check valves 72 useful in the present invention are known to those skilled in the art. The pressure regulator 73 is a valve comprising a smaller orifice than that present in the check valve 72 to provide a tortuous path for the fluid exiting the expansion chamber 54 and entering the annular space 75 so that the transition is smooth from the higher pressure in the expansion chamber 54 required for initial expansion of the lower portion of the lower casing string 32 to the lower pressure in the expansion chamber 54 required to maintain expansion up the length of the lower casing string 32 (see FIG. 2B). The pressure regulator 73 is preferably a jetted valve, which is known by those skilled in the art.

[0039] Referring again to FIGS. 1A-C, the expander tool 2 further includes an upper spline assembly 10 for axial translation of the expandable members 15. Specifically, the upper spline assembly 10 includes an upper outer spline 60 coupled to an upper inner spline 61 using a third spline connection 59. Preferably, the upper outer spline 60 and the upper inner spline 61 are tubular shaped. The third spline connection 59 allows the upper inner spline 61 to extend/retract axially relative to the upper outer spline 60. A lower portion of the upper inner spline 61 is rotatably connected to an upper portion of the lower inner spline 50 using a thrust bearing assembly 62. The thrust bearing assembly 62 allows the lower spline assembly 49 and the upper spline assembly 10 to rotate independently of each other. Although a thrust bearing assembly 62 is used, other apparatus capable of
allowing the spline assemblies 49 and 10 to rotate independently as known to a person of ordinary skill in the art are also applicable.

[0040] A lower portion of the upper inner spline 61 has threads 63 that engage helical threads 64 formed on an outer surface of the rotatable mandrel 3. A nut 66 having threads 63 is attached to the upper inner spline 61 for engaging the rotatable mandrel 3. The helical threads 64 are formed along a pre-determined length of the outer surface of the rotatable mandrel 3. A connector 65 on the upper portion of the upper outer spline 60 connects the upper spline assembly 10 to the upper running tool (not shown) with the torque anchor (not shown) thereon, thereby causing the upper spline assembly 10 to be rotationally fixed within the wellbore. In this manner, as the rotatable mandrel 3 is rotated, the threads 63 of the upper inner spline 61 may ride along the helical threads 64 of the rotatable mandrel 3 and axially advance the upper inner spline 61. Suitable torque anchors for use with the present invention are well known in the art. The torque anchor moves axially, but not rotationally, relative to the upper casing string 31.

[0041] FIGS. 1A, B, and C, FIGS. 2A, B, and C, and FIG. 3 show the expansion system at various stages in the expansion process. In operation, a torque anchor (not shown) is placed on a casing working string (not shown) along with the expander tool 2 and the lower casing string 32. The expander tool 2 is located at the lower end of the casing working string, while the torque anchor is located at the upper end of the casing working string. The casing working string is temporarily connected to the lower casing string 32 to accomplish the expansion operation in a single trip. In this manner, the lower string of casing 32 can be introduced into the wellbore at the same time as the expander tool 2.

[0042] Prior to lowering the expander tool 2 into the wellbore, a predetermined amount of hydraulic fluid is injected into the expansion chamber 54 of the expander tool 2. In the unactuated position shown in FIGS. 1A-C, the pressure inside the expansion chamber 54 is insufficient to actuate the expandable members 15. During run-in of the expander tool 2, the expandable members 15 reside in the recesses 17.

[0043] The expander tool 2, lower casing string 32, and torque anchor are lowered into the wellbore on the casing working string. The expander tool 2 is lowered with the lower spline assembly 49 in a retracted position and the upper spline assembly 10 in an extended position. As the expander tool 2 is lowered into the wellbore, the first pressure regulation system 5 operates to equalize pressure between the expansion chamber 54 and the annular space 47 between the expander tool 2 and the wellbore. In the open position of the first pressure regulation system 5 shown in FIG. 1C, fluid flows from the annular space 47, through the first valve 57, into the fluid recess 90, and into the expansion chamber 54 when the pressure outside the expansion chamber 54 is higher than the pressure inside the expansion chamber 54. Similarly, fluid flows from the expansion chamber 54, into the fluid recess 90, through the second valve 58, and into the annular space 47 when the pressure within the expansion chamber 54 is higher than the pressure outside the expansion chamber 54.

[0044] After the lower casing string 32 is lowered to the desired depth within the wellbore, the torque anchor is activated so that the torque anchor remains stationary during the rotation of the rotatable mandrel 3. The torque anchor is rotationally fixed relative to the upper casing string 31 when activated.

[0045] Actuation of the expander tool 15 begins with the rotation of the casing working string. It is contemplated that rotation of the rotatable mandrel 3 is accomplished by rotating the casing working string from the surface. However, rotation may also be achieved by activation of a downhole rotary motor, such as a mud motor. Rotating the casing working string causes the rotatable mandrel 3 to rotate. The first spline connection 52 transfers the torque from the rotatable mandrel 3 to the lower spline assembly 49, thereby causing the expandable members 15 to rotate about the inner surface of the lower casing string 32. Rotating the mandrel 3 also initiates the axial advancement of the expandable members 15. As the rotatable mandrel 3 rotates, the threads 63 on the upper inner spline 61 ride along the helical threads 64 of the rotatable mandrel 3. Being rotationally fixed, the upper inner spline 61 is advanced axially relative to the upper outer spline 60 and the rotatable mandrel 3 as its threads 63 engage the threads 64 of the rotatable mandrel 3. Connected to the upper inner spline 61, the lower inner spline 50 and the expandable members 15 are pulled along by the upper inner spline 61. Even though the lower inner spline 50 is traveling axially, it must be noted that the lower inner spline 50 continues to rotate with the rotatable mandrel 3 due to the thrust bearing assembly 62.

[0046] The axial advancement of the lower inner spline 50 causes the first pressure regulation system 5 located thereon to travel upward. FIG. 2C shows the first pressure regulation system 5 moved upward relative to FIG. 1C upon activation of the expander tool 2. When the expander tool 2 begins operating, the first pressure regulation system 5 is isolated so that fluid no longer travels between the annular space 47 and the expansion chamber 54. Isolation occurs when the lower inner spline 50 advances axially and the fluid recess 90 is no longer in fluid communication with a recess 91 located on the inner diameter of the lower inner spline 50 adjacent to the first and second valves 57 and 58. In this way, fluid pressure is permitted to build up within the expansion chamber 54 to force the expandable members 15 to extend outward and expand the lower casing string 32. FIG. 2C shows the first pressure regulation system 5 in the isolated position, as fluid flow through the recess 91 is blocked by the inner diameter of the rotatable mandrel 3. Isolation of the first pressure regulation system 5 eliminates the first and second valves 57 and 58 as leak paths so that pressure can build up within the expansion chamber 54.

[0047] As shown in FIG. 1B, the expandable members 15 reside in the recesses 17 until the fluid pressure in the expansion chamber 54 rises above the initial pressure required for actuation of the expandable members 15. Once the first pressure regulation system 5 is isolated, the continued axial advancement of the lower inner spline 50 triggers an increase in hydraulic pressure in the expansion chamber 54. Axial advancement of the lower inner spline 50 relative to the second pressure regulation system 70 compresses the fluid in the expansion chamber 54, thereby causing a gradual increase in hydraulic pressure in the expansion chamber 54. The friction member 71 blocks the relief of the pressurized fluid from the expansion chamber 54 into the annular space 75. The pressure increase behind the expandable members
15 provides the pressure necessary for expansion. The pressure gradually extends the expandable members 15 against the lower casing string 32, so that the lower casing string 32 is expanded radially by the torque of the casing working string. This stage in the expansion process is shown in FIGS. 2A, 2B, and 2C.

[0048] The pressure continues to rise until it reaches the optimum expansion pressure. The optimum expansion pressure is reached when expansion of the lower casing string 32 is constrained by the upper casing string 31, herein termed the constraint point. At the constraint point, the length of the lower casing string 32 is expanded against the upper casing string 31 as shown in FIG. 3. Once the optimum expansion pressure is reached, the flange member 71 breaks and bleeds off fluid from the expansion chamber 54 to regulate the pressure in the expansion chamber 54. In the embodiment shown in FIG. 5, fluid travels from the expansion chamber 54, through the broken flange member 71, through the check valve 72, into the pressure regulator 73, and into the annular space 75. Again, in the alternative embodiment shown in FIG. 4, the fluid travels from the expansion chamber 54, through the unobstructed flange member 71, through the check valve 72, and into the annular space 75.

[0049] In the preferred embodiment, the pressure regulator 73 increases the ability of the check valve 72 to cycle open to closed, thus regulating pressure to a greater extent. Increased regulation of pressure through the pressure regulator 73 provides a smoother transition from the initial, higher pressure required for initial expansion of the lower casing string 32 to the lower pressure necessary to maintain the expansion of the remaining length of the lower casing string 32. The pressure regulator 73 regulates the fluid volume allowed to travel through the check valve 72 through jetting (choking) action of a tortuous path of fluid. A small orifice within the pressure regulator 73 provides the tortuous path for the fluid so that a sudden, large amount of fluid pressure is not allowed to travel through the check valve 72 directly into the annular space 75. The pressure regulator 73 permits the check valve 72 to work more quickly to achieve a steady state of reduced pressure and thereafter maintains the fluid pressure at a steady rate. Placing the pressure regulator 73 downstream of the check valve 72 creates a back pressure on the check valve 73, increasing the open/closed response time of the check valve 73 and producing increased pressure stability within the expansion chamber 54 of the expander tool 2. Increasing pressure stability and the open/closed response time controls fluid loss, produces a smoother transition from the higher, initial pressure and the lower, maintained pressure, and maintains a more stable, predefined pressure at the constraint point.

[0050] The second pressure regulation system 70 controls the pressure exerted on the expansion members 15 and translated to the lower casing string 32, thus preventing excessive wall thinning. The second pressure regulation system 70 parameters may be easily altered based upon the tensile strength and thickness of the material of the tubular to be expanded.

[0051] FIG. 3 shows the expander tool 2 near the end of the expansion process. At this point, the upper spline assembly 10 is in a retracted position and the lower spline assembly 49 is in an extended position. The lower inner spline 50 has moved the lower seals 56 past the mandrel taper 55. Disengaged from the mandrel taper 55, the lower seals 56 are no longer capable of retaining fluid in the expansion chamber 54. The leakage of fluid relieves the pressure in the expansion chamber 54, thereby deactivating the expansion members 15. After the expansion members 15 have returned to their respective recesses 17, the torque anchor is deactivated and the collet is released from the lower casing string 32. Thereafter, the expander tool 2 may be retrieved by pulling on the casing working string.

[0052] While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

1. A method for expanding a tubular within a wellbore, comprising:
   attaching an expander tool to the lower end of a working string, the expander tool comprising an expansion chamber in fluid communication with a flange member in series with a valve;
   running the working string with the expander tool into the wellbore;
   expanding the tubular at a first pressure into substantial contact with a casing wall of the wellbore; and
   expanding the tubular at a second pressure.
2. The method of claim 1, wherein the first pressure is higher than the second pressure.
3. The method of claim 1, wherein the flange member breaks before expanding the tubular at a second pressure.
4. The method of claim 3, wherein the valve operates after the flange member breaks.
5. The method of claim 1, wherein the flange member is a burst plug.
6. The method of claim 1, wherein the valve is a check valve.
7. The method of claim 1, wherein the expander tool further comprises a regulator valve in fluid communication with the expansion chamber.
8. The method of claim 7, wherein the regulator valve creates a back pressure on the flange member in series with the valve, thereby increasing response time of the valve.
9. The method of claim 1, wherein the expander tool further comprises at least two valves which regulate differential pressure between the expansion chamber of the expander tool and an exterior of the expander tool while running the working string with the expander tool into the wellbore.
10. The method of claim 9, wherein the at least two valves comprise a first valve which allows fluid to flow into the exterior of the expander tool.
11. The method of claim 10, wherein the at least two valves further comprise a second valve which allows fluid to flow into the expansion chamber.
12. The method of claim 9, further comprising the step of substantially obstructing flow through the at least two valves before the step of expanding the tubular at a first pressure into substantial contact with a casing wall.
13. The method of claim 12, wherein the substantially obstructing flow through at least two valves further comprises plugging openings of the at least two valves.

14. An expander tool for expanding a tubular body, the expander tool comprising:
- an expansion chamber; and
- a frangible member in series with a valve in fluid communication with the expansion chamber.

15. The expander tool of claim 14, further comprising a regulator valve in fluid communication with the expansion chamber.

16. The expander tool of claim 15, wherein the regulator valve is located downstream of the frangible member in series with the valve.

17. The expander tool of claim 14, wherein the frangible member bursts upon constraint of the expander tool.

18. The expander tool of claim 14, wherein the frangible member is a burst plug.

19. The expander tool of claim 14, wherein the valve regulates fluid flow at a reduced rate after the frangible member bursts upon constraint.

20. The expander tool of claim 15, wherein the regulator valve operates through a jetting action of a tortuous path of fluid.

21. The expander tool of claim 15, wherein the regulator valve creates a back pressure on the frangible member in series with the valve.

22. The expander tool of claim 15, wherein the regulator valve is a jetted valve.

23. The expander tool of claim 14, further comprising at least two valves disposed inside the expansion chamber.

24. The expander tool of claim 23, wherein the at least two valves regulate differential pressure between the expansion chamber and an outside of the expander tool.

25. The expander tool of claim 24, wherein the at least two valves comprise a first valve which permits pressure from the expansion chamber to release into the outside of the expander tool.

26. The expander tool of claim 25, wherein the at least two valves further comprise a second valve which permits pressure from the outside of the expander tool to release into the expansion chamber.

27. An expander tool comprising:
- means for expanding a tubular at a first pressure until the tubular contacts a casing wall of a wellbore; and
- means for expanding a tubular at a second pressure after the tubular contacts the casing wall of the wellbore.

28. The expander tool of claim 27, wherein the first pressure is higher than the second pressure.

29. The expander tool of claim 28, further comprising means for regulating the transition between the means for expanding the tubular at the first pressure and the means for expanding the tubular at a second pressure.

30. The expander tool of claim 27, further comprising means for decreasing differential pressure between an inside portion of the expander tool and an outside portion of the expander tool.

31. A method for expanding a tubular within a wellbore, comprising:
- running a working string into the wellbore with an expander tool attached to the lower end, the expander tool comprising:
  - an expansion chamber in fluid communication with a frangible member in series with a check valve; and
  - at least two valves;
- regulating differential pressure between the expansion chamber and an exterior of the expander tool with the at least two valves while running the working string into the wellbore;
- expanding the tubular at a first pressure into substantial contact with a casing wall of the wellbore;
- allowing sufficient pressure to break the frangible member to accumulate within the expansion chamber; and
- expanding the tubular at a second pressure.

32. An expander tool for expanding a tubular body within a wellbore, the expander tool comprising:
- an expansion chamber comprising two valves which regulate differential pressure between an inside of the expansion chamber and an outside of the expansion chamber; and
- a frangible member in series with a valve in fluid communication with the inside of the expansion chamber.

33. The expander tool of claim 32, further comprising a regulator valve located downstream of the frangible member, wherein the regulator valve is in fluid communication with the expansion chamber.